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Effects of dietary protein replacement of fishmeal with mealworm meal on growth, feed utilisation, survival and colour enhancement of Goldfish, *Carassius auratus*

***Mousumi Das**

Department of Zoology, Vidyasagar College, Kolkata- 700006 (India)
Email: mousumidasghosh23@gmail.com
Telephone Number: +91-8777866313

Abstract

A six-month laboratory trial was conducted to assess the effects of dietary replacement of fishmeal protein with mealworm (*Tenebrio molitor*) meal at 0% (control), 25% (D25), 50% (D50), 75% (D75) and 100% (D100) level on growth efficiency, feed utilization parameters, survival percentage and total carotenoid deposition in skin and muscle tissue of goldfish (*Carassius auratus*). Fifteen experimental units were comprising of five dietary treatments, each with three replications and each aquarium was stocked with 30 juveniles of goldfish (mean weight 0.57±0.03 gm). At the end of the experimental period, goldfish juveniles fed with the D50 diet exhibited significantly higher final weight (7.22±0.15 gm) followed by the D75 set (6.52±0.10 gm) and then in the D0 set (5.43±0.15 gm), whereas lowest value was recorded in the D100 (4.62±0.11 gm). Significantly higher length of goldfish was noted in the D50 set (8.87±0.09 cm) and lower in the D100 set (5.82±0.07 cm). Maximum value of specific growth rate (SGR) was noticed in the D50 set and the lowest in the D100 set. Feed conversion ratio (FCR) of the control was 4.02±0.11 whereas best FCR was noted in the D50 diet fed set (3.01±0.08) and the poorest in the D100 set (4.86±0.17). So, with the escalating percentage of fishmeal replacement with mealworm meal above 50% led to significant depletion in growth efficiency and feed utilization. Survival percentage was ranged from 96.67% to 54.44%, with a higher mean value in D50 set and significantly lower in D100 set. Total carotenoid content in fish skin and muscle tissue, was significantly higher (25.20±0.40) in D50 set and lower in D100 set (4.91±0.18), whereas significantly appreciative value was noted in the D25 (9.64±0.17) when comparing with the control (6.20±0.19). Thus, 50% fishmeal protein replacement with mealworm meal at an inclusion amount of 22.29gm in 100gm diet will be suitable for goldfish, *C. auratus.*

Key words : Carotenoid content, fishmeal, goldfish, growth efficiency, mealworm, survival percentage.

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*Assistant Professor,

Ornamental fish culture, a crucial part of aquaculture, not only provide aesthetic value but also earn foreign exchange. It has a positive impact on developing countries' economy as it provides employment to the rural people and its retail value is much higher than of the trade value[9]. The growing demand of aquarium fishes have resulted in a steady increase in the ornamental fish industry globally, with a value of approximately US$15 billion[56].

Among the worldwide-well-recognized ornamental fishes, goldfish (*Carassius auratus*) is one of the commercially desired species due to its colours, shape and size, and also of its wide range of tolerance[36]. The skin pigmentation of goldfish is a key quality that determines its market value and consumer acceptability[22]. Its brilliant reddish-orange colour is acquired from the carotenoid deposition in its skin and muscle tissue. Though fishes are unable to synthesize carotenoid de novo[30], absorb their requirement from dietary sources[17]. Carotenoid not only enhance skin colouration of ornamental fishes but also accelerate growth performance and increase fish tolerance to environmental conditions[38]. In ornamental aquaculture carotenoid must be incorporated through dietary supplementation[9] as earlier studies proved that faded colouration of ornamental fishes were due to carotenoid-deficient diets[22,64]. In the commercial feed for farmed ornamental fishes, incorporation of synthetic carotenoid such as astaxanthin (red) and canthaxanthin (orange-red) are commonly practiced[14,42]. Standardized synthetic carotenoids are expensive and increases the feed cost 10% to 20%[16]. Due to their high-cost, current commercial market approaches towards natural carotenoid sources[23]. Some crustaceans like krill, shrimps, artemia, lobster, copepods, water fleas, are able to deposit excellent amount of carotenoid in their body[9,17,28,51,57,62], could be the natural animal-based carotenoid sources. Prior studies depicted that the natural cost-effective carotenoid sources are the alternative to synthetic carotenoid compounds for ornamental fish feed industries and could be incorporated in the fish feed to improve fish skin pigmentation[39].

Over the last decade, a number of studies have pursued to boost the profitability of ornamental fish industry by improving their production efficiency and enhancing their skin pigmentation through the incorporation of various non-conventional, alternative, carotenoid-loaded, cheap, easily available animal protein sources by manipulating ornamental fish nutrition[10, 11,14]. Dietary protein of fish feed, is an important nutrient of fish nutrition. Proper growth and colouration of ornamental fishes relies on the quality and appropriate quantity of dietary protein[19]. Aqua-feed cost mostly depends on the cost of primary protein source used in feed[6]. In aquaculture, fish feed is most expensive input[24] due to high cost of fishmeal which is the most accepted primary protein source of fish feed due to its nutritional profile and its quality protein and amino acid composition[68]. The increasing cost of fishmeal and its scarcity due to its upscaling demand, resulted to the search for non-conventional alternative cost-effective animal protein sources with a good amount of natural carotenoids that could replace fish meal completely or partially in the fish feed.

One of such alternative potential

protein sources in aquafeed is mealworm (*Tenebrio molitor*) larvae, could be a principal ingredient for replacing the fishmeal in fish feed. The mealworm larvae having about 47% to 60% crude protein and about 18% to 30% crude lipid[21] of dry matter with excellent amino acid and fatty acid profile[16] make them suitable for inclusion in animal and fish feed[43,58]. Prior studies of feeding trial with mealworm provided conflicting reports regarding its suitable dietary inclusion level[35].

Therefore, the present study aimed to estimate the effect of diets replacing fishmeal protein with mealworm meal at different percentages on the growth efficiency, feed utilization, survival and the carotenoid concentration in the skin and muscle tissue of goldfish, *Carassius auratus*.

Experimental fish :

A six-month feeding trial was carried out at the laboratory of Department of Zoology, Vidyasagar College, West Bengal, India, using 500 juveniles of goldfish with an average initial weight of 0.57±0.03 gm. Fishes were purchased from a local ornamental fish market in March, 2022 and acclimatized for 15 days in a glass aquarium (36"×12"×12") in the laboratory facilities and conditions, fed on a commercial diet. Following the acclimatization period, fishes were randomly captured and distributed in 15 experimental glass aquariums (18"×12"×12") in triplicate of five sets at a density of 30 fishes per aquarium. Diets were given twice daily (09:00 and 18:00) to the fishes, at the amount of 4% of body weight per day. The extra uneaten feed particles were collected, dried and weighted to find out the amount of diet consumed daily. Total water exchange was done twice a week.

Experimental diet :

Dried mealworm larvae were purchased from nearby local pet shop (Kolkata, India) and then oven-dried at 40ºC for 48 hours in the laboratory, and then ground into powder form. It was kept in airtight zipper plastic bags until further use in preparing experimental diets for feeding trial and analysis. Five iso-proteic experimental diets were formulated to meet the nutritional requirement of goldfish. A practical fishmeal-based diet was designated with 38% crude protein, was used as control (D0), and the four other diets were formulated to contain 11.14%, 22.29%, 33.43% and 44.57% mealworm, replacing 25%, 50%, 75% and 100% of fishmeal protein and named as D25, D50, D75 and D100 diets respectively. For the preparation of each experimental diet, all the oven-dried ingredients were finely ground, well mixed and thoroughly blended with double-distilled water into dough, and pelleted by pelletizer through 2 mm die. The obtained moist stands were oven dried at 40ºC for 24 hours and then crushed into desirable particle size and kept in room temperature in airtight bags until used. Dietary ingredients proportion and proximate composition of all the experimental diets were tabulated in Table-3.

Proximate composition analysis :

For the estimation of crude protein, crude lipid, crude fibre, moisture, ash contents of mealworm larvae and experimental diets, proximate composition was carried out according to the guideline of Association of Official Analytical Chemists methods[4].

Growth efficiency :

At the termination of the six-months feeding trial, fishes were counted in each aquarium and starved for 24 hours. Then final weight and length of fishes were recorded and the growth efficiency parameters like weight gain, specific growth rate (SGR%), and food utilization parameters in terms of total food consumption and feed conversion ratio (FCR) were calculated.

Estimation of carotenoid :

Carotenoid content of experimental diets were estimated by Cyanotech[13] method and the total carotenoid content of coloured part of fish skin and muscle tissue were measured by following Olson[47] method.

Water quality analysis :

Physico-chemical parameters of water like temperature, dissolved oxygen, pH, free carbon dioxide, hardness, alkalinity and total dissolved solids (TDS) of experimental aquariums were analysed and recorded throughout the experimental period using standard methods[5].

Statistical analysis :

The results were presented in tables and figures as mean ± standard error of the mean (SE). Statistical analyses for all the data were done by using one-way analysis of variance (ANOVA) followed by Duncan's multiple range tests (DMRT) to separate the mean values according to significance.

Water quality parameters :

Table-1. Physico-chemical water quality parameters of experimental aquarium sets during the experiment

Parameter	Minimum	Maximum
Temperature (°C)	27	39
Dissolved Oxygen (ppm)	8.1	8.4
pH	7.2	7.4
Free Carbon dioxide (ppm)	1.46	2.22
Hardness (ppm)	595	655
Alkalinity (ppm)	320	336
TDS (ppm)	910	1060

The data-range of water physico-chemical parameters of all the experimental aquariums were tabulated in Table-1. Dissolve oxygen, free carbon dioxide, temperature and pH of the water of experimental aquarium were within the normal range, but values of water hardness, alkalinity and TDS were little higher.

Nutrient composition of experimental meals:

Table-2. Proximate nutritional composition of mealworms meal and fishmeal (%, dry weight basis).

Nutritional composition (%)	Mealworm meal	Fishmeal
Crude Protein	49.00±0.72a	52.00±0.93b
Crude Lipid	17.78±0.80b	13.14±1.61a
Crude Fibre	7.26±0.36b	5.01±0.53a
Ash	4.71±0.03a	13.02±1.26b
Moisture	6.02±0.14a	18.96±1.04b
NFE	21.24±0.98b	16.83±2.36a

Data are presented as mean ± SE. Different letters (a,b) in a row denote significance difference ($P<0.05$) indicated by one-way ANOVA followed by DMRT.

Proximate compositions in terms of crude protein, crude lipid, crude fibre, ash and moisture of mealworm meal and fishmeal were presented in table-2. Crude protein percentage of mealworm meal was significantly lower than the fishmeal protein percentage, whereas crude lipid and crude fibre percentage on dry weight basis was found higher in mealworm meal. Ash and Moisture content in percentage was observed higher in fishmeal.

Table-3. Ingredients, their proportion and proximate composition of experimental diets

Diet ingredients (gm/100gm)	D0	D25	D50	D75	D100
Fishmeal	42.00	31.50	21.00	10.50	0.00
Mealworm	0.00	11.14	22.29	33.43	44.57
Soybean	21.50	21.50	21.50	21.50	21.50
Corn	7.00	7.00	7.00	7.00	7.00
MOC*	14.50	14.50	14.50	14.50	14.50
Rice bran	12.50	9.18	7.61	6.70	6.04
Wheat	0.50	3.18	4.10	4.37	4.39
Vitamin-Mineral Premix*	2.00	2.00	2.00	2.00	2.00
Total	100	100	100	100	100
Crude Protein	38	37.9	37.82	37.75	37.68
Crude lipid	15.34	15.42	15.57	15.81	16.22
Ash	12.55	11.35	10.45	9.37	8.12
Crude Fibre	9.27	10.79	11.46	13.55	13.73
NFE	24.84	24.54	24.7	23.52	24.25

*MOC- mustard oil cake

*Vitamin-Mineral Premix (mg/kg diet): retinol-18,000 IU, Choleclaciferol-2000 IU, thiamine-15, menadione sodium bisulphate-10, riboflavin-25, pyridoxine-5, α-tocopherol-35, nicotinic acid-200, Ca-pantothenate-50, biotin-1.5, folic acid-10, cyanocobalamin-0.03, ascorbyl monophosphate-50, inositol-400, copper sulphate-20.2, dibasic calcium phosphate-5.9, sodium fluoride-2.21, potassium iodide-0.78, zinc oxide-37.5, ironsulphate-200, magnesium oxide-840, manganese oxide-26, cobalt sulphate-1.85, sodium selenite-0.65, potassium chloride-1.17, sodium chloride-0.45.

The ingredient composition and proximate compositions of experimental diets were given in table-3. The proximate compositions of all the experimental diets of goldfish did not vary remarkably and the protein percentage on dry weight basis was ranged from 37.68% to 38%. (Table-3).

Growth performance :

Table-4. Growth parameters of goldfish, *Carassius auratus* fed with different mealworm diets in six months feeding trial

Growth parameters	Diets				
	D0	D25	D50	D75	D100
Initial length (cm)	2.75±0.03a	2.78±0.04a	2.77±0.07a	2.67±0.08a	2.77±0.03a
Final length (cm)	7.52±0.06c	6.60±0.06b	8.87±0.09e	7.75±0.05d	5.82±0.07a
Initial weight (gm)	0.56±0.03a	0.56±0.02a	0.58±0.03a	0.60±0.02a	0.57±0.04a
Final weight (gm)	5.43±0.15c	4.88±0.14b	7.22±0.15e	6.52±0.10d	4.62±0.11a
Weight gain (gm)	4.88±0.13c	4.32±0.12b	6.65±0.18e	5.92±0.09d	4.05±0.14a
SGR (%)	1.27±0.01c	1.20±0.02b	1.41±0.04e	1.33±0.01d	1.16±0.05a
Total food consumption (gm)	19.60±0.01c	19.12±0.01b	21.34±0.32e	19.95±0.04d	18.65±0.05a
FCR	4.02±0.11c	4.43±0.12d	3.01±0.08a	3.38±0.050b	4.86±0.17e

Values are mean ± SE. Values with different letters are significantly different ($P<0.05$) using DMRT after one way ANOVA.

Table-4 presented the results of growth efficiency and feed utilization parameters of the goldfish, noted at the termination of six-month experimental period. At the beginning of the experiment, the initial length and the initial weight were taken, which were varied from 2.5 cm to 2.9 cm and 0.50 gm to 0.62 gm respectively. At the end of feeding trial, the final length and the final weight was significantly higher in the D50 set followed by the D75 set, whereas the results of both the parameters of control (D0) were higher than the values of the D25 and the D100 sets and significantly lowest final length and final weight was recorded in the D100 diet fed set. Weight gain in gram was found highest in goldfishes fed with mealworm meal of 50% inclusion (D50) while 75% inclusion of mealworm (D75) meal gained second highest weight, and then in the 100% fish meal diet (D0) and lowest weight gain was observed in the 100% mealworm meal inclusion set (D100). The best value of specific growth rate in percent SGR (%) was found in the D50 diet fed set and poorest in the D100 set, but the D75 set showed a better value when comparing with the control (D0). Positive effect of all the experimental diets except the D100 was observed for the feed utilization of the experimental fishes. In case of food consumption, goldfishes of the D50 set consumed significantly highest amount of food followed by the fishes of the D75 set and then in the D0 set and the lowest amount of food was eaten by the experimental fishes of the D100 set. The best value of the FCR was found in the D50 diet, containing mealworm meal at the 50% replacement of fishmeal, but significantly highest value of FCR was observed in the D100 set.

Survival percentage :

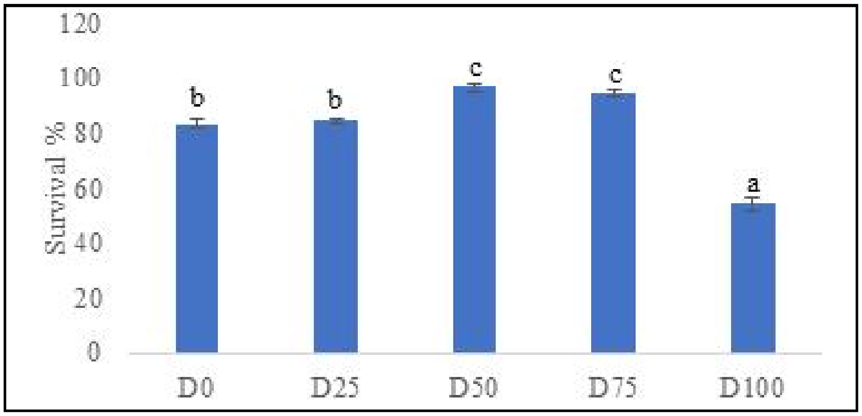

Figure 1. Survival percent of *C. auratus* fed with five experimental diets. Values are mean ± SE. Bars with different letters are significantly different (P<0.05) using DMRT after one way ANOVA.

Inclusion of mealworm meal in the diet of the goldfish showed a positive impact on the survival percentage which was ranged from 54.44% to 96.67%. Goldfish fed with the D50 diet showed a higher mean survival percentage whereas the values of the D50 set did not vary significantly with the D75 set (Fig. 1). Survival percentage of the D25 set and the D0 set also vary insignificantly. Here 100% fishmeal replacement with mealworm showed lowest value of survival percentage.

Carotenoid content of fish meal and in fish skin and tissue :

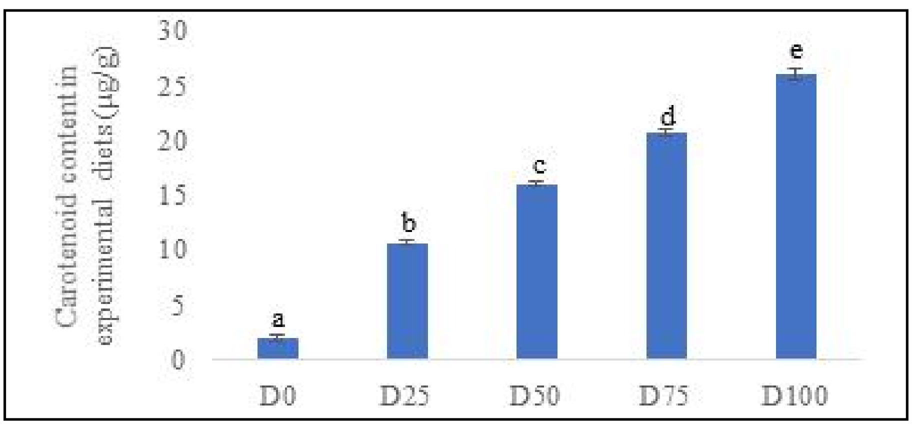

Figure 2. Carotenoid content (µg/g) in five experimental diets. Values are mean ± SE. Bars with different letters are significantly different (P<0.05) using DMRT after one way ANOVA.

The spectrophotometric analysis of carotenoid content of goldfish meals was measured and the highest value was found in the D100 meal where 100% fishmeal replaced by mealworm meal, followed by the D75, D50, D25 and the lowest in the D0 where 0% inclusion of mealworm meal. This result was the direct consequence of the escalated percentage of mealworm inclusion (Fig. 2).

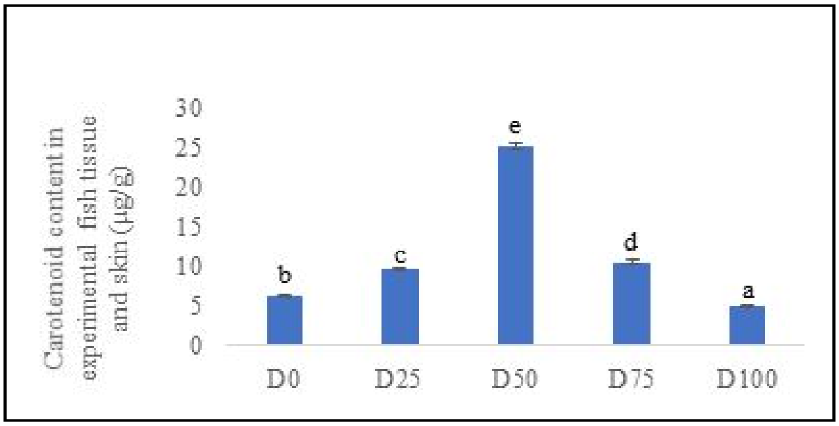

Figure 3. Carotenoid content (µg/g) in five experimental diets fed fish tissue and skin. Values are mean ± SE. Bars with different letters are significantly different ($P<0.05$) using DMRT after one way ANOVA.

Among the five experimental diet sets, concentration of carotenoid deposition in the body of goldfishes was found significantly higher in the D50 diet fed fishes, followed by the D75 set, and then in the D25 set. Whereas the fishes of the D25 set, showed higher carotenoid deposition in their body when comparing with the control (D0) and significantly lowest value of carotenoid content in fish body was observed in the D100 diet fed set (Fig. 3).

In case of physico-chemical water quality parameters of experimental aquariums, the value-range of water hardness and TDS of ground water of experimental area used in the aquariums, were 595ppm to 655 ppm and 910 ppm to 1060 ppm respectively, which were quite higher than the normal range. But any adverse effect on growth efficiency parameters and survival percentage of goldfish during the acclimatization period was not observed. This observation was confirmed by the previous studies, where depicted that ornamental fishes are able to tolerate a wide range of hardness and TDS[23,49].

When considering the growth and food utilization by gold fish it was observed that with the surge of the level of food consumption, values of growth efficiency parameters escalated accordingly. This investigation was asserted the observation of Johnston *et al*.[37] and Sapkale *et al*.[60] where denoted that higher growth was obtained with the increased food consumption by *X. maculatus*. Higher consumption of diets corresponded with higher weight gain and higher growth of selected fish[53]. The results of the growth efficiency and food utilization parameters in terms of weight gain, SGR, total food consumption and FCR were noted superior in the goldfishes fed on the D50 diet where 50% fishmeal protein was replaced by the mealworm meal protein, followed by the D75, D0, D25 and the poorest in the D100 where 100% fishmeal protein was replaced by the mealworm meal protein. Therefore, the 50% substitution of fishmeal protein with mealworm meal protein in the diet was found best for goldfish, which was also noted suitable for rainbow trout[8], black spot seabream[31], Asian seabass[1]. Moreover, the present study revealed that up to 75% fishmeal protein could be replaced by the mealworm meal protein. Few prior studies also reported that the acceptable results of growth of yellow catfish were obtained when fishes were fed on diet with 75% inclusion of mealworm meal[67]. Jeong *et al.*,[34] conducted a feeding trial on Black porgi (*Acanthopagrus schlegelii*) and published that 60% replacement of fishmeal with mealworm meal could be possible which was supported by Harsij *et al.*,[27], Antonopoulou *et al.*,[3] and Basto *et al.*,[7] in case of rainbow trout, gilthead sea bream (*Sparus aurata*), European sea bass (*Dicentrarchus labrax*). In this context, the present study differed from few prior reports, where noted that the diet of 80% fishmeal replacement with mealworm meal displayed a better growth and feed utilization in Catfish (*Clarias gariepinus*)[46].

In the current study, significantly poorest results for weight gain, food intake, SGR and FCR were observed in the 100% replacement of fishmeal with mealworm meal. This observation was supported by Redman *et al.*,[54] in black sea bass and Mazlum *et al.*,[44], in narrow-clawed crayfish juveniles where in 100% fishmeal replacement, fishes showed disinterest in feeding and consumed significantly less amount of diet that led to significantly poorest results for growth efficiency. This observation opposed the observations of Saravanan *et al.*,[61] and Ido *et al.*,[32] where reported that 100% fishmeal replacement in diet displayed significantly best result in the final body weight, food intake, SGR (%) and FCR of rainbow trout and Red Seabream respectively.

In the earlier studies it was observed that in the fish diet, the level of fishmeal replacement with the mealworm meal, for their better growth and food utilization, varied greatly among the fish species. This variation of mealworm meal inclusion level in fish diet was might be species specific.

In case of survival percentage, 100% fishmeal replacement with the mealworm meal resulted the lowest survival percentage (see Figure 1) that result was asserted by Ido *et al.*,[32] in red seabream but differed from the results of Mazlum *et al.*,[44] in narrow-clawed crayfish juveniles, where survival percentage was significantly higher in 100% fishmeal replacement set. The fishes fed the diet of 50% fishmeal replacement with the mealworm meal showed best value for survival percentage. A similar result was found in rainbow trout and European seabass, where higher survival percentages were obtained from 50% fishmeal replacement with the mealworm meal[63].

Carotenoid not only enhance the pigmentation of fish skin but also have a positive influence in nutrient metabolism[54] which ultimately improve the growth of fish[61]. Present study endorsed this investigation as significantly highest values of both the carotenoid content in fish body and growth performance parameters were found in the D50 set. This is might be due to the natural carotenoid, present in the diet that may be responsible in promoting growth. During carotenoid metabolism in fishes, vitamin A and some nutrients are formed which function as growth promoter[29]. Few prior studies also accepted this opinion and showed that the amount of carotenoid content in fish feed directly related with their growth enhancement, as found in red sword tail[63], rainbow trout[15], goldfish[64] and in guppy fish[45]. According to Yesilayel *et al.*,[74] fish were able to utilize feed carotenoid. This was found in goldfish[26,71] when fed diet with some natural carotenoid sources.

In addition, earlier investigation reported that carotenoid deposition in fish body directly related with dietary carotenoid content which ultimately increase pigmentation. This was observed when goldfish were fed with various natural carotenoid sources like spirulina, red yeast and alfalfa[41, 72, 73].

A definite concentration of carotenoid in diet plays an important role in their absorption and deposition in fish body[66, 69]. In the present study, the concentration of carotenoid in the D50 diet was 25.2 μg/gm which might be the suitable concentration of carotenoid in diet that would be the cause of highest growth and skin pigmentation of goldfishes of that set. Though the carotenoid concentrations in the D75 and the D25 diet could be also allowable as in this concentration acceptable growth and also skin pigmentation of fish were noticed. This particular carotenoid concentration in feed at which the carotenoid deposition in fish tissue and skin was maximum, is species specific[22]. Therefore, the extreme level of carotenoid content in fish tissue and skin is precise which is attained by taking an optimum quantity of carotenoid through feed[2]. Over that quantity of carotenoid in feed did not show any increase in carotenoid deposition in fish tissue and skin, rather provide a negative impact on carotenoid deposition in fish body as well as in fish growth[33].

In last decade, several researches on ornamental fishes were carried out with different carotenoid sources like blue green algae and spirulina and some plant sources like beet root[63], tomato and carrot[45] and paprika[26] in fish feed and documented that carotenoid in fish feed greatly influenced colour development in ornamental fishes. Though, various plant carotenoid sources have been incorporated in the diet of ornamental fishes, inclusion of natural carotenoid from animal sources are very limited in aqua-feed. Hence, in the present investigation, mealworm meal, a nonconventional sustainable insect protein source with suitable amount of carotenoid were incorporated at different percentages in fish feed which showed not only significant effect in skin colouration but also on growth, food utilization and survival percentage of goldfish.

Several research works were conducted to establish the feasibility and efficiency of mealworm meal inclusion partially or completely in aqua-feed of different fish species and revealed that dietary mealworm inclusion did not affect their growth performances negatively[3,7,12,20,43,50,52,55,59,65,70]. The earlier reports on the suitable level of fishmeal replacement with the mealworm meal that support the best growth performances were contradictory. Few feeding trials recommended that the highest level of replacement of fishmeal with mealworm meal could not be more than 25 – 30% [40,59,67], whereas other noticed outstanding results at more than 80% replacement[32,46]. The appropriate level of fishmeal replacement with mealworm meal might be species specific[48].

The results of the present experiment elucidate that the experimental goldfishes were able to efficiently utilize mealworm meal protein as well as its carotenoid. Dietary substitution of fishmeal with mealworm meal at 50% level improve growth and survival of the fish, and promoted efficient carotenoid concentration in skin and tissue of goldfish. Moreover, mealworm meal could be incorporated in the diet of goldfish up to 75% of fishmeal replacement without any negative influence on growth, survival and skin pigmentation of the fishes. Therefore, the outcome of this study is of special importance in ornamental fish culture. Hence, follow-up research works should be conducted aiming at optimizing the potential percentage of the mealworm meal replacing the fishmeal in the fish feed. Therefore, need more feeding trials with other ornamental fish species for obtaining suitable level of mealworm meal inclusion which is species-specific and also require more future investigations for exploring novel cost-effective insect protein sources that could able to replace high-cost fishmeal in aqua-feed which will ultimately support aquarium trade of India.

References :

1. Alghada, D., E. Ebrahimi, Y. Keivany and S.A.H. Jalali (2022). *Iranian Journal Ichthyology 9*(3): 165-174.
2. Amla, A., D. Villar-Martinez, C. Juan, O. Rogel, E. Pablo, V. Espinoza, G. Adrian, Q. Gutierrez and M. Lara-Flores (2013). *Research Journal of Fisheries and Hydrobiology 8*(2): 31-37.
3. Antonopoulou, E., E. Nikouli, G. Piccolo, L. Gasco, Gai F., Chatzifotis S., Mente E. and K.A. Kormas (2019). *Aquaculture 503:* 628–635.
4. AOAC. (2006). Official methods of analysis. 18th ed. Revised. Washington, DC, USA: Association of Official Analytical Chemists.
5. APHA. (1989). Standard methods for examination of water and waste water American Public Health Assoc., pp. 1452 Washington, DC.
6. Aragão, C., A.T. Gonçalves, B. Costas, R. Azeredo, M.J. Xavier and S. Engrola (2022). *Animals 12:* 1-41.
7. Basto, A., E. Matos and L.M.P. Valente (2020). *Aquaculture 521:* 735085.
8. Belforti, M., F. Gai, C. Lussiana, M. Renna, V. Malfatto, L. Rotolo and I. Zoccarato (2015). *Italian Journal of Animal Science 14:* 670–676.
9. Bell, N.A., S. Jeffrey, J.L. MacIsaac and S.M. Colombo (2019). 13(100187): 1-5.
10. Besen, K.P., E.W.H. Melim, L. Cunha, E.D. Favaretto, M. Moreira and T.P. Fabregat (2019). *Aquaculture Research 2:* 1–7.
11. Boonyaratpalin, M. and N Unprasert (1989). *Aquaculture 79:* 375–380.

12. Choi, I.H., J.M. Kim, N.J. Kim, J.D. Kim, C. Park, J.H. Park and T.H. Chung (2018). *Acta Scientiarum-Animal Sciences 40:* 1–9.
13. Cyanotech. (2002). Analysis of Beta-carotene and total carotenoids from spirulina (Spectrophotometric method). Spirulina pacifica. Technical Bulletin, 003b, Cyanotech corporation.
14. Dananjaya, S.H.S., P. Manjula, A.S. Dissanayake, M. Edussuriya, K. Radampola, B.K. Park and M.D. Zoysa (2019). *Journal of Applied Aquaculture 32*(1): 1-17.
15. De-la, M.G.I., J.L. Arredondo-Figueroa, J.T. Ponce-Palafox, I.A. Barriga-Sosa and J.E. Vernon-Carter (2006). *Aquaculture 258:* 487-495.
16. De-Marco, M., S. Martínez, F. Hernandez, J. Madrid, F. Gai F, L. Rotolo, M. Belforti, D. Bergero, H. Katz, S. Dabbou, A. Kovitvadhi, I. Zoccarato, I. Gasco and A. Schiavone (2015). M.Sc. thesis, pp. 68 Graduate School of Natural and Applied Sciences, Mersin University.
18. El-Ouny, Y.M., S. Maulu, M.A. Zaki, A.A. Helaly, A.M. Nour, M.F. ElBasuini, E.H. Labib, R.H. Khalil, A.H. Gouda, A.A. Hessein, M. Verdegem and H.S. Khali (2023). *Aquaculture Reports 29:* 1-9.
19. Erdogan, F., M. Erdogan and E. Gümüs (2012). *Turkish Journal of Fisheries and Aquatic Science 12:* 635-640.
20. Feng, Y., X.M. Chen and M. Zhao (2018). *Insect Science 25:* 184-98.
21. Gasco, L., M. Finke and A. van-Huis (2018). *Journal of Insects as Food and Feed 4*(1): 1-4.
22. Gouveia, L. and P. Rema (2005). *Aquaculture Nutrition 11:* 19-23.
23. Gumus, E., C. Gurler and I. Gulle (2022). *Indian Journal of Fisheries 69*(1): 121-129.
24. Gurung, S., K. Bohara, R. Adhikari, A. Bista and S. Singh (2018). *Journal of Institute of Agriculture and Animal Science 35:* 277-284.
25. Ha, B.S., D.S. Kang, J.H. Kim, O.S. Choi and H.Y. Ryu (1993). *Bulletin of the Korean Society of Fisheries Technology 38:* 331–338.
26. Hancz, C., I. Magyary, T. Molnar, S. Sato, P. Horn and N. Taniguchi (2003). *Fishery Science 69*(6): 1158-1161.
27. Harsij, M., H. Adineh, R. Maleknejad, H. Jafaryan and M. Asadi (2019). *Journal of Fishery Science and Technology 8:* 137–143.
28. Hekimoglu, M.A. (2005). *Journal of Fisheries and Aquatic Science 22*(1): 137-141.
29. Henry, M., L. Gasco, G. Piccolo and E. Fountoulaki (2015). *Animal Feed Science and Technology 203:* 1–22.
30. Higuera-Ciapara, I., L. Felix-Valenxuel and F. oycoolea (2006). *Critical Reviews in Food Science and Nutrition 14:* 185–196.
31. Iaconisi, V., S. Marono, G. Parisi, L. Gasco, L. Genovese, G. Maricchiolo and G. Piccolo (2017). *Aquaculture 476:* 49–58.
32. Ido, A., A. Hashizume, T. Ohta, T. Takahashi, C. Miura and T. Miura (2019). *Animals 9*(3): 100-112.
33. Jagadeesh, T.D., H.S. Murthy, S.V. Surendranath, P. Panikkar, N. Manjappa and V. Mahesh (2015). *The Bioscan 10*(3): 1431-1435.
34. Jeong, S.M., S. Khosravi, K.W. Kim, B.J. Lee, S.W. Hur, S.G. You and S.M. Lee (2022). *Aquaculture Reports 22*(100956): 1-8.
35. Jeong, S.M., S. Khosravi, K.Y. Yoon, K.W.

Kim, B.J. Lee, S.W. Hur and S.M. Lee (2021). *Aquaculture Reports 1747:* 1-13.

36. Jia, Y., Y. Liu, K. Chen, H. Sun and Y. Chen (2019). *Aquatic Invasions 14:* 724–737.
37. Johnston, G., H. Kaiser, T. Hecht and L. Oellermann (2003). *Journal of Applied Ichthyology 19:* 40-43.
38. Kargýn, H. and M.D. Dikbaş (2020). *Siberian Journal of Life Science Agriculture 12*(5): 62-78.
39. Kaur, R. and T.K. Shah (2017). *International Journal of Fisheries and Aquatic Studies (5):* 684–686.
40. Khosravi, S., E. Kim, Y.S. Lee and S.M. Lee (2018). *Journal of Science and Technology 27:* 133-139.
42. Maiti, M., D. Bora, T.L. Nandeesha, S. Sahoo, B.K. Adarsh and S. Kumar (2017). *International Journal of Fisheries and Aquatic Studies 5*(4): 340-345.
43. Mastoraki, M., P. Mollá-Ferrándiz, S.C. Vardali, D.C. Kontodimas, Y.P. Kotzamanis, L. Gasco, S. Chatzifotis and E. Antonopoulou (2020). *Aquaculture 528:* 735511.
44. Mazlum, Y., F. Turan and Y.B. Yıldırım (2021). *Aquaculture Research 00:* 1–9.
45. Mirzaee, S., A. Sabani, S. Rezaee and M. Hosseinzadeh (2012). *Global Veterinary 9*(2): 171-174.
46. Ng, W.K., F.L. Liew, L.P. Ang and K.W. Wong (2001). *Aquaculture Research 32:* 273–280.
47. Olson, A.A. (1979). *Nutrition Reports International 19:* 807-813.
48. Osimani, A., C. Garofalo, V. Milanovi´c, M. Taccari, F. Cardinali, L. Aquilanti, M. Pasquini, M. Mozzon, N. Raffaelli, S. Ruschioni, P. Riolo, N. Isidoro and F. Clementi (2016). *European Food Research and Technology 243:* 1157-1171.
49. Pailan, G.H., A. Sinha and M. Kumar (2012). *Indian Journal of Animal Nutrition 29*(3): 291-296.
50. Panini, R.L., L.E.L. Freitas, A.M. Guimaraes, C. Rios, M.F.D. Silva, F.N. Vieira and C.P. Silva (2017). *Aquaculture 473:* 115–120.
51. Pattanaik, S.S., P.B. Sawant, M.K.A. Xavier, P.P. Srivastava, K. Dube, B.T. Sawant and N.K. Chadha (2021). *Aquaculture 534:* 736303e.
52. Piccolo, G., S. Marono, L. Gasco, F. Iannaccone, F. Bovera and A. Nizza (2014). Insects to Feed the World, pp. 76 The Netherlands, Wageningen University.
53. Rad, F., G. Koksal and M. Kindir (2003). *Turkish Journal of Veterinary and Animal Science 27:* 1085-1090.
54. Redman, D.H., D. A. Nelson, J. Roy, R. Goldberg, T.M. Scott, B. Michael, M.B. Rust and R. Mercaldo-Allen (2019). NOAA Technical Memorandum, pp. 1-20 NMFS-NE-253.
55. Rema, P., S. Saravanan, B. Armenjon, C. Motte and J. Dias (2019). *Animals 9*(4): 180-187.
56. Rhyne, A.L., M.F. Tlusty, J.T. Szczebak and R.J. Holmberg (2017). *Peer J 5*(e2949): 1-36.
57. Roncarati, A., F. Sirri, A. Felici, L. Stocchi, P. Melotti and A. Meluzzi (2016). *Italian Journal of Animal Science 10*(2): e27.
58. Sánchez-muros, M., F.G. Barroso, F and Manzano-agugliaro (2014). *Journal Cleaner Production 65:* 16–27.
59. Sankian, Z., S. Khosravi, Y.O. Kim and S.M. Lee (2018). *Aquaculture 496:* 79–87.
60. Sapkale, P.H., S.V. Patil, S.R. Yadav and M.J. Gitte (2017). *Ecology, Environment*

and Conservation 23(4): 2125-2128.

61. Saravanan, S., B. Armenjon, A. Hubert, F. Berro, P. Rema and J. Dias (2015). *In Aquaculture Europe European Aquaculture Society: Rotterdam, The Netherlands 880:* 766–767.
62. Seidgar, M., F. Mohebbi, A. Nekuiefard, M. Hafezieh, S. Dadgar, A. A. Anbi and A. Shiri (2019). *International Journal of Aquatic Science 10*(2): 88-93.
63. Singh, R.N. and A. Kumar (2016). *Imperial Journal of Interdisciplinary Research 2*(10): 637-642.
64. Sinha, A. and O.A Asimi (2007). *Aquaculture Research 38:* 1123-1128.
65. Song, Y.S., M.W. Kim and C. Moon (2018). *Entomology Research 48:* 227-33.
66. Storebakken, T. and H.K. No (1992). Pigmentation of rainbow trout. *Aquaculture 100*(1-3): 209-229.
67. Su, J., Y. Gong, S. Cao, F. Lu, D. Han, H. Liu and S. Xie (2017). *Fish Shellfish Immunology 69:* 59–66.
68. Tacon, A.G.J. and M. Metian (2015). *Rev Fish Sci Aquaculture 23*(1): 1-10.
69. Torrissen, O.J., R.W. Hardy and K.D. Shearer (1989). *Aquatic Science 1:* 209-225.
70. Tubin, J.S.B., D. Paiano, G.S. Hashimoto, O. de, W.E. Furtado, M.L. Martins and E. Durigon (2020). *Aquaculture 519:* 734-736.
71. Wallat, G.K., A.M. Lazur and F.A. Chapman (2005). *North American Journal of Aquaculture 67:* 42-51.
72. Xu, X., Z. Jin, H. Wang, X. Chen, C. Wang and S. Yu (2006). *Journal of World Aquaculture Society 37:* 282-288.
73. Yanar, M., Z. Erçen, A.O. Hunt and H.M. Buyükçapar (2008). *Aquaculture 284:* 196-200.
74. Yeşilayer N., O. Aral, Z. Karsli, M. Öz, A. Karaçuha and F. Yağci (2010). *Israeli Journal of Aquaculture 63:* 1–9.